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EFFECTS OF INITIAL MOISTURE CONTENT ON BOIL BENDING PROPERTIES OF SOLID RUBBERWOOD (HEVEA BRASILIENSIS)

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Effects of initial moisture content on boil bending properties of solid rubberwood
(Hevea Brasiliensis)

By

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Dedicated to: All my family members

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

In recent years, there has been a high demand for rubberwood in the wood based industry in Malaysia, and this demand is expected to increase further. Inefficient use of resources not only leads to higher production cost but also increases the demand for industrial wood supply. Currently, most of the furniture makers in Malaysia are trying to cut down their production cost in order to maintain a competitive edge. One way to reduce production cost is to use the technique of steam or boil bending of solid rubberwood. This can increase the wood utilization efficiency by 30%, simplify of production process and enable greater process automation. This study was carried out to investigate the effects of initial moisture content on boil bending properties of rubberwood, specifically comparing the percentage and type of defects. Initial wood moisture contents of below 10% and 20-25% were used to investigate the boil bending properties of rubberwood. The recovery rate of boil bending of solid rubberwood was found to improve by about 6% when the initial wood moisture content was increased from 10% to 20-25%. In order to minimize the production cost, it is recommended to use initial wood moisture content of 20-25% instead of the current practice of below 10%.

CHAPTER ONE

INTRODUCTION

1.1 Background

Solid wood bending method was developed in Europe and became popular in the 1850's when a large steam bent furniture manufacturer started to produce curved pieces of timber (Kingston, 1939). Wood bending is defined as a process of making a permanent curved item by steaming or boiling (Anon, 1990). The method of solid wood steam or boil bending is considered the cheapest and simplest method of fabricating curved wood items. It is more economical than machining because material wastes are considerably reduced (Makinaga, Norimoto and Inoue, 1997). Forest Products Research and Development Institute (FPRDI) have conducted an economic feasibility study to determine the economic advantage of solid wood bending method compared to band sawing method. The results show that solid wood bending can result in a saving of 64% to 94% in raw material. (Anon, 1990, Appendix A).

Steam or boil bending has been widely used for the production of curve pieces of timber for furniture, boat building, sporting goods, tool handles and industrial timber. While there are other methods commonly used for creating curved timber structures including glue lamination (gluing together thin sections of wood) and cutting curves from a solid section of wood. Steam bending has advantages over other methods as lamination involves the loss of over two thirds of the wood used and a large amount of glue is required, while cutting curves from solid wood incurs a considerable quantity of waste and the shapes created are of limited strength due to the presence of a large amount of cross grain. For example, a sweeping curve on the back leg of a chair can be very weak if it is cut from a wide solid laminated board. A portion of the leg will inevitably be short grain and prone to failure if it is subjected to any stress. With boil or steam bending, the same leg will retain virtually all of the strength of the original straight piece of wood. Glue lamination of a curve from thin strips of wood may cause problems when finish materials are applied. Any glue that is exposed during shaping will not accept the final finish in the same way as the wood. The laminates are always under stress and, if some are cut away during shaping, the curvature may change. The steam bent timbers have no memory of ever being any other shape unless immersed in water. The grain will also follow the curve and virtually reinforce the shape created as illustrated in Figure 1.

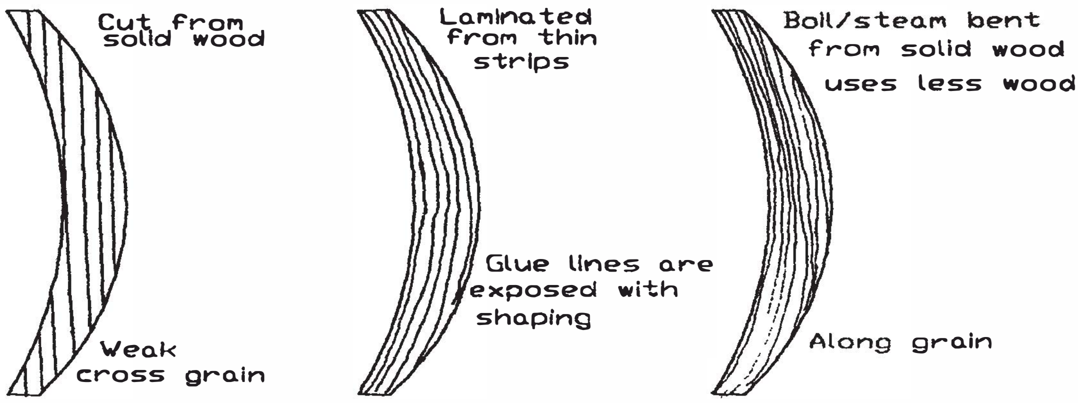

Figure 1: Illustration of wood grain orientation in curved wooden structures prepared using different methods

1.2 Justification

One of the fastest growing sectors in Malaysia is the wood based industry, which has contributed significantly to foreign exchange earning. Malaysia is now the world's 15^{th} largest furniture exporter, although its two percents share of US100 billion global wooden furniture markets is relatively small. Rubberwood is the main raw material for the Malaysia furniture industries. Malaysia Timber Industry Board (MTIB) estimated that 85% of the wooden furniture exports are made from rubberwood (Asia Timber, 2000).

The resource use efficiency in furniture industries not only would determine the production cost but also the demand for industrial wood supply. Currently, most of the furniture makers are trying to cut down their production cost in order to maintain a competitive edge. One way to reduce production cost is to use the technique of steam or boil bending of solid rubber wood because it can increase the wood utilization efficiency by 30%, simplify of production process and higher enable greater process automation. However, there is a lack of fundamental data to provide a profound understanding on the technique used to bend the solid rubberwood. In current practice, most of the furniture manufacturers use kiln dried wood with moisture content of less than 10% and the rejection rate of wood bending process is about 10%, which is considered very high for the wood based industry.

One of the factors that affect the result of the boil bending of solid wood is the level of moisture content. Woods in green condition or freshly cut timber should be seasoned to moisture content of 20-25% before bending (Anon, 1990). Since one of the most important factors to produce the furniture with a competitive price is to minimize the reject of material used, it is necessary to investigate the effects of initial moisture content on the steam or boil bending properties of rubberwood.

1.3 Objective

The main objective of this study was to investigate the effects of initial moisture contents (<10% and 20-25%) on the boil bending properties of rubberwood.

CHAPTER TWO

LITERATURE REVIEW

2.1 The principles of wood bending

In the bending of wood or other elastic materials, it is usual to assume that transverse plane sections remain plane and normal to the longitudinal fibres, i.e. end sections initially square with the faces of a piece remain square during the process of bending (Stevens and Turner, 1970). For wood in the bent state, the lengths of the convex and concave faces are no longer equal as they were when originally cut. The difference in these lengths is brought about by induced compressive stresses, which cause the fibres on the concave face to shorten, and induced tensile stresses that cause the fibres on the convex face to stretch. This distortion was caused by stresses, which also tend to bring the bent piece to original straightness when the force is released (Anon, 1990).

The most important point in wood bending is to deform the wood in the plastic range, which was above the modulus of elasticity (MOE) and below the modulus of rapture (MOR) as illustrated in Figure 2. Modulus of elasticity is a measurement of stiffness at proportional limit ratio of stress to strain (Haygreen and Bowyer, 1982), While MOR is used to determine the maximum load applied to a piece wood before failure occurs.

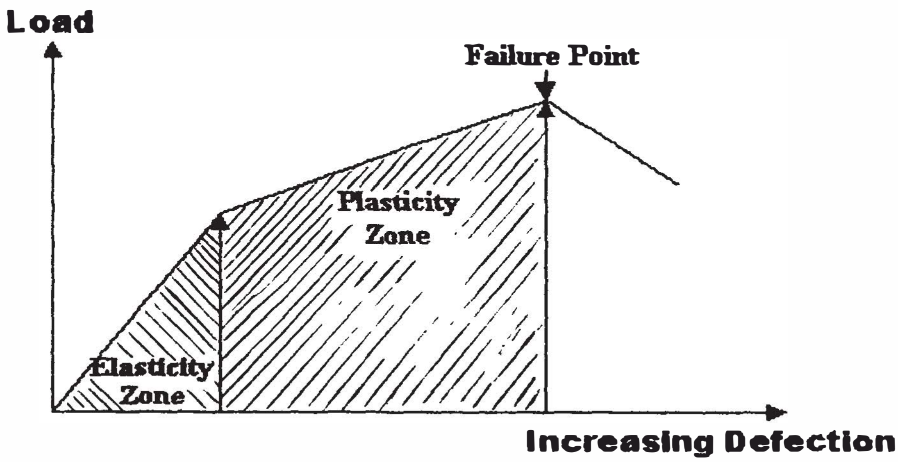

Figure 2: Stress-strain diagram illustrate the behavior of wood

Wood behaved elastically and plastically when it was above and below the proportional limit respectively as shown in Figure 2 (Wengert, 1999). Within the elasticity zone, the wood would move to its original shape when the bending force was removed. The wood would form a permanent deformation when it was within the plasticity zone. However, the wood would failed when was exceeded the plasticity zone (Wengert, 1999).

Most timbers in their natural state could not be bent to a small radius of curvature without either fracturing or retaining elastic properties sufficient to cause them to spring back to their original shape on removal of the bending forces. However, some species when subjected to heat in the presence of moisture (usually by steaming or boiling) become semi-plastic and their compressibility was very considerably increased (Stevens and Turner, 1970). In this state, comparatively small compressive stresses were capable of producing appreciable strains without fracturing the material. Normally, a flat piece of untreated wood could tolerate a difference of 2% to 3% the internal and external prior to failing (Wengert, 1999).

Heat treatment has much less effect on the tensile properties of these woods and the limiting radius of curvature becomes dependent on the maximum permissible tensile stress and the strain of the stretched fibres on the convex face (Stevens and Turner, 1970). Wood that has been softened in steam or boiled water could be compressed in the longitudinal direction to a considerably greater extent than untreated wood. Moreover, the softened and compressed material after cooling could be bent to a smaller radius than steamed hot but uncompressed wood (Steven and Dean, 1966). The steamed or boiled wood would become more plastic in compression and able to accept more deformation without failure (Wengert, 1999). The radius obtained with heat treatment would be smaller as greater shortening of the fibres near the concave face may occur before the breaking point in tension was reached compared to untreated wood. The neutral axis of untreated wood was unchanged in length and situated at the midway between the convex and concave surface. While the neutral axis of treated wood was moved towards the convex surface so that the proportion of the wood in tension was reduced and increased in compression as shown in Figure 3 (Stevens and Turner, 1970).

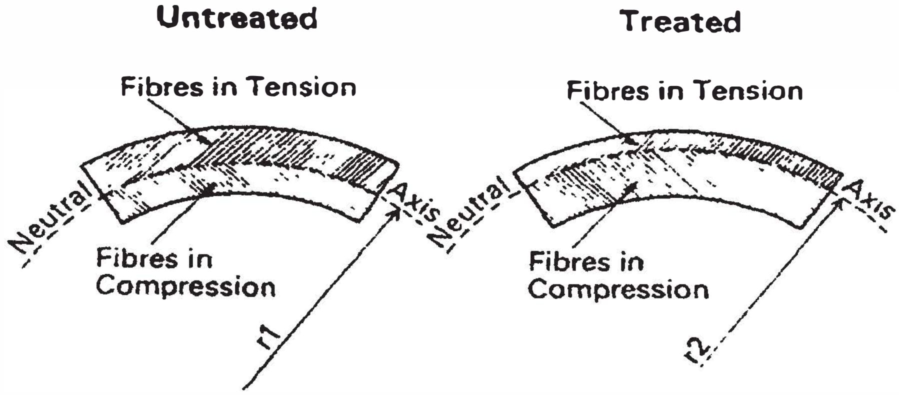

Figure 3: Effect of steaming treatment on the position of the neutral axis in a bend

The precise mechanism involved in the plastic deformation of stressed heat-treated wood is not fully understood, nor could be stated with certainty why some timbers were considerably more responsive to such treatment than others. There was even variation within a same species due to uneven wood grain (Lee, 1998). In general, most of the temperate zone hardwoods react favorably to heat treatment in the presence of moisture but many of the tropical hardwoods and most of the softwoods were refractory in this respect and hence were not so suitable for bending in solid form (Stevens and Turner, 1970).

In order to ensure the success of solid wood bending, a supporting strap was used to reduce the tension in the outer radius and kept the wood under compression during the bending process. A study was carried out to investigate the steamed bent rubberwood properties with and without using metal supporting strap. The result shows the radius of curvature obtained for both radial and tangential with metal supporting strap were 500mm. While, based on the criterion of 95% faultless bends, the limiting radius of curvature for radial and tangential specimens without metal supporting strap were 700mm and 675mm respectively as shown in Appendix B (Ser and Lim, 1980).

2.2 Factors influencing the boil bending of solid rubberwood

Basically, there are a number of factors that affect the result of the boil bending of solid wood. Among the major factors are quality, species, softening treatment and moisture content of the wood. Almost all of these parameters interact with each other in one way or another.

2.2.1 Quality of raw material

Wood of good quality is one of the main factors to be considered in a successful bending operation. Care in selecting wood for bending was essential and the wood should be free from defects such as knots, ingrown bark, surface checks, pitch and cross grain wood. The use of defective wood should be avoided as much as possible to minimize losses due to failure of the wood in bending. The best material used in order to produce a relatively small radius of curvature should be those with straight grains and free from defects (Anon, 1990)

2.2.2 Species of timber

Most of the temperate hardwood species react more favorably to heat treatment in the presence of moisture compared to softwood and tropical hardwoods. The bending properties of a large number of different timbers have been compiled from the results of tests carried out at the Forest Products Research Laboratory (Stevens and Turner, 1970). For example, the smallest radius of curvature could be bent using beech (*Fagus sylvatica*) from temperate hardwood and sepetir (*Pseudosindora palustris*) from tropical hardwood were 41mm and 460mm respectively.

2.2.3 Moisture content

Moisture content influences the bending properties of wood. Most species could be bent in the green state to a small radius of curvature, however its were ruptured as a result of hydraulic pressures built up within the moisture-laden cells (Stevens and Turner, 1970). The rough sawn timber should be partially air dried to moisture content of around 15 to 20% before bending (Bootle, 1971). The beech wood could be bent to 41mm of radius successfully when the wood moisture content was between 20% and 30% (Lee, 1998). Experience at Forest Products Research and Development Institute (FPRDI) was showed that bending wood with moisture content of 25% to 30% was most advantageous (Anon, 1990). Woods in green condition or freshly cut timber should be seasoned to moisture content of 25% to 30% before bending. Kiln dried wood with moisture content of below 20% must be soaked in cold water overnight or longer, until the moisture content reaches 25% to 30%.

2.2.4 Softening treatments

It was very important to make the wood semi plastic before bending. Although wood could be plasticized chemically or even by microwaves when in a green state, the most convenient way to make the wood become semi-plastic with increased compressibility was by steaming or boiling. Lignin and hemicelluloses are naturally occurring substances in which hold the wood cells together. Imagine the wood fibers to be a bundle of rods with the space between them filled with lignin and hemicelluloses. The celluloses are polymers that behave the same as thermoplastic resins. Wood subjected to heat treatment could decrease the strength of this lignin bond between the rods. Steaming or boiling at 100°C for one hour per inch of thickness (regardless of the width) would soften the bond enough for bending. Substantial over-steaming may cause the wood to wrinkle on the concave face as the bend progresses (Lee, 1998). Heat and moisture together could produce a degree of plasticity, which is roughly 10 times that of dry wood at normal temperature (Anon, 1990).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental Materials

3.1.1 Wood material

Rubberwood (*Hevea brasiliensis*) with two levels of initial moisture content (<10% and 20-25%) were used in this study. A total of 250 pieces of rubberwood with initial moisture content of below 10% (control) and 20-25% were extracted from kiln dry plant at *Consistent Pattern Sdn Bhd, Lot 211/210, Phase 2, Kawasan Perusahaan Kuala Ketil, 09300 Kedah.*

3.1.2 Equipment and tools

The machine used for this study was a multiple opening hot press with a curvature radius of 800mm as shown in Figure 4.

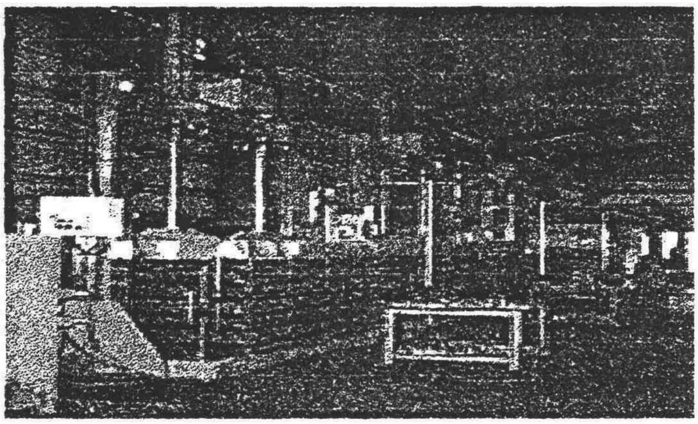

Figure 4: Multiple opening Hot Press Machine

An aluminum boiling tank was used in order to prevent rusty after boiling the water over a period of time. A metal supporting strap was used to stop the wood from stretching on the outside face during the bending process as shown in Figure 5.

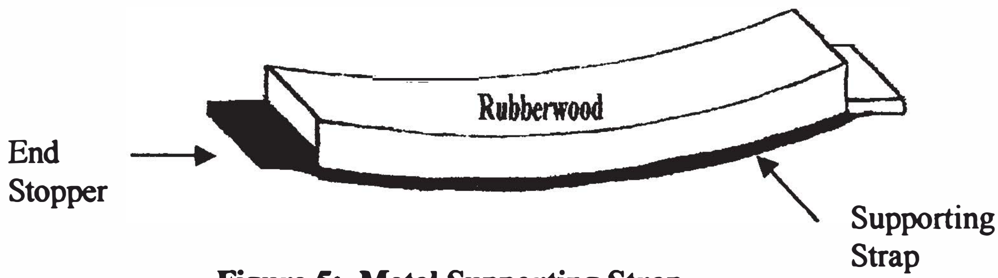

Figure 5: Metal Supporting Strap

3.2 Manufacturing process flow of boil bending for rubberwood

The summary of manufacturing process flowchart is shown in Appendix C.

3.2.1 Material preparation

A total of 500 pieces pressure treated (PT) green rubberwoods (1" x 4" x 18") were used as raw material for this study. The PT green rubberwood was kiln dried at a commercial plant. When the moisture content reached between 20-25%, 250 pieces of kiln-dried rubberwoods were extracted, and the remaining was dried by using kiln-drying schedule to moisture content of below 10%. The raw materials was sent to machining section for S4S surface moulding to a thickness of 23mm, width of 98mm, and crosscut to a length of 450mm. Spindle moulders were used to shape the S4S rubberwood to the required furniture component's shape such as backrest and backrest supporter.

3.2.2 Inspection

Before the rubberwood samples were put into the boiling tank, the moisture content and the quality were inspected. The inspection of wood quality was carried out by visual inspection grading such as grain orientation, surface check, pitch and knots based on conventional practice in the furniture industries as shown in Appendix D. The percentage of moisture content of the wood after boiling was determined by oven-dry method:

$$\% \text{ Moisture Content} = \frac{\text{Green weight} - \text{OD weight}}{\text{OD Weight}} \times 100\%$$

The moisture content reading and quality of rubberwood samples were also inspected after hot pressing.

3.2.3 Boiling time

The setting of the boiling time was based on one hour per inch of thickness regardless of the wood's width and length. The component parts were boiled at 100^0C over 54 minutes.

3.2.4 Metal supporting strap

The time taken for the immediate processing is to ensure a successful boil bending because when woods cool down after boiling, the strength of lignin bond